

Prioritization of Abandoned Mines in the Animas Watershed, Southwestern Colorado

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ABSTRACT

More than two thousand abandoned mines within the Animas watershed in Southwestern Colorado are being prioritized for remediation by the Animas River Stakeholders Group (ARSG). Phased collection and assessment of information progressed from large scale to site specific. Prioritization was based on existing or potential environmental impact and technical feasibility of remediation as measured by dissolved Cd, Cu, and/or Zn in the discharge; indicators of habitat degradation; aquatic life in streams; cumulative impacts at the point of compliance; cost effectiveness; treatability/feasibility; and cultural and historic preservation.

ACKNOWLEDGMENTS

This work is a summary of the prioritization activities of the Animas River Stakeholders Group (ARSG). The ARSG is composed of local residents, mining companies, local and state government agencies, and federal agencies including the US Forest Service, the Bureau of Land Management, the U.S. Geological Survey, the Bureau of Reclamation, the Corps of Engineers, and the Environmental Protection Agency. These stakeholders are bound together by their common interests in the Animas Watershed. The prioritization is a work in progress and this summary may not represent the final decisions of this group.

INTRODUCTION

In 1860 members of the John Baker party made the first mineral discovery in the Upper Animas Basin surrounding the current town of Silverton, Colorado (Burbank, et al, 1968). Not until a new treaty between the Federal government and the Ute Indians was the region thrown open to settlement and mineral production. From 1870 to 1991 underground mining from the Silverton area produced millions of dollars worth of silver, gold, lead and zinc and tens of thousands of tons of waste material. Given the large number of mining and milling sites and the current technologies for remediation, sufficient resources may never be available to clean up all of these sites in the Animas Watershed. Therefore the Animas River Stakeholders Group (ARSG) came together to jointly set priorities to yield the greatest benefits in the most cost-effective manner. By evaluating water quality data the ARSG established priorities in a consistent, rigorous manner: from the watershed level to major stream segments, from tributaries to individual sources targeted for remediation.

OBJECTIVES

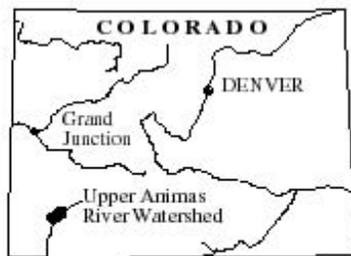
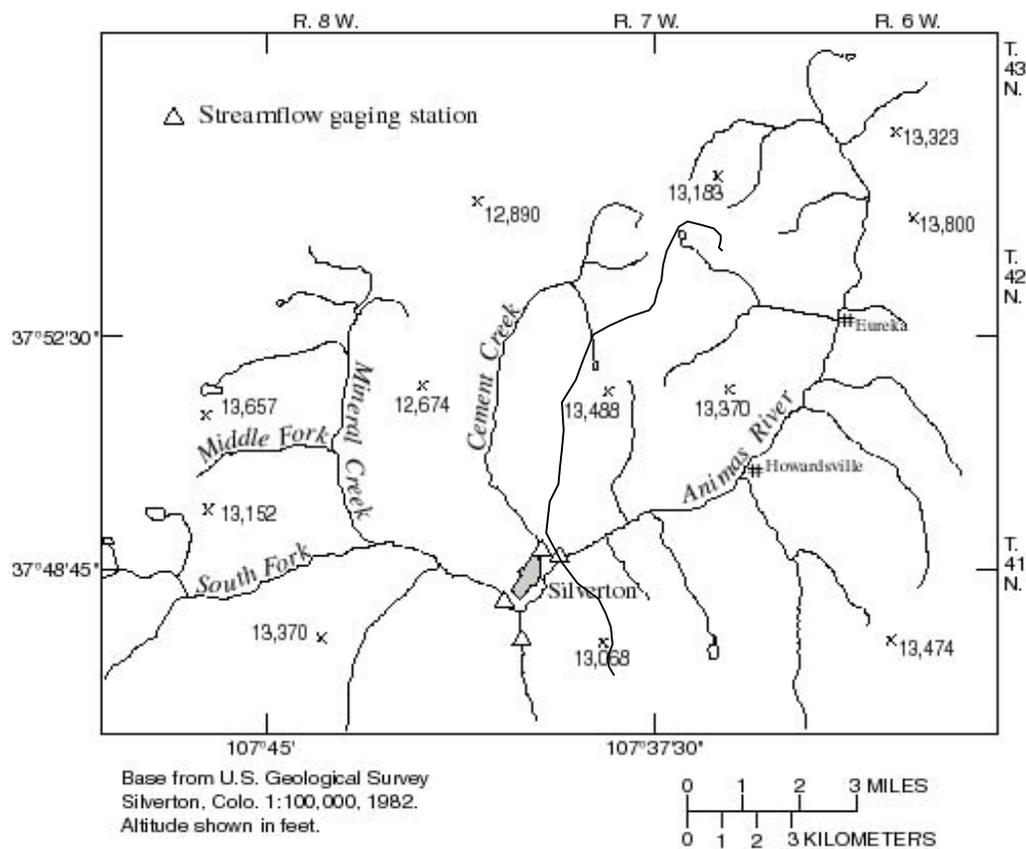
The objectives of the Animas River Stakeholders Group (ARSG) prioritization are to:

- identify major sources of environmental problems from over 2,000 abandoned mine sites identified within the watershed,
- determine the relative contributions of metal loading to the river from these sources, and
- improve water quality, where and when possible, at these sites.

BACKGROUND

In order to understand the prioritization process undertaken by the ARSG, one must understand a little of the regulatory background of water quality evaluation. First, we struggled to come to a mutual understanding of the water quality problem and how the regulatory system measures water quality. Public perceptions of risk and the process of prioritization were intimately linked. Scientists shared their understanding of the scientific and technical aspects of environmental risk while the public conveyed their concerns and the bases for their community value system.

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LOCATION MAP



Figure 1 Maps of Colorado and the upper Animas area focusing in on priority areas. (ARCS, 1999)

Water Quality

In practice, EPA defines water quality by laws passed to protect water quality, such as the Clean Water Act (CWA) and the Safe Drinking Water Act (SDWA). In these laws water quality is measured by how well the water supports existing or designated uses of the water. Designated uses are established in State or Tribal water quality standards regulations, and these uses can serve to describe the desired condition for water resources. The States or Tribes set water quality standards with guidance and approval by the EPA. The guidance provided to the states is based upon criteria, which reflect the most current scientific information available regarding pollutant effects on human health and aquatic life. This information is published in the “gold book” as quantitative concentrations or qualitative assessments of pollutants in water that would protect uses of the water (EPA, 1996). In the case of the Animas, there was little information on the existing uses of the water: because few fish populations were documented in the watershed and the water is not used as a drinking water supply. Therefore, the State set out to designate uses or, in other words, establish water quality goals.

Site Specific Standards. Standards can be based on information that reflects environmental conditions at that particular site. For example, site-specific standards may be appropriate where species inhabiting a given site may be more or less sensitive than those used by EPA in deriving “gold book” values, the water chemistry differs significantly from the water used in the lab, or no studies were done for that particular chemical (EPA, 1996).

Use Attainability Analyses. States perform use attainability analyses (UAA) to determine achievable uses of a waterbody. A UAA is a structured scientific assessment of the physical, chemical, biological, and economic factors that affect the attainment of a use. A UAA is a particularly useful tool in situations where the “fishable/swimmable” goal uses of the Clean Water Act are not currently being met (EPA, 1994). The UAA, in such cases, can be used to answer the questions:

- What is the potential for this waterbody?
- What are the stressors limiting that potential?
- Are those stressors controllable?

Total Maximum Daily Loads. Another consideration if the waters are not meeting water quality goals is the requirement that States identify impaired waters (CWA Section 303(d)) (EPA, 1994). A Total Maximum Daily Load (TMDL) must be calculated to: 1) determine the maximum amount of a pollutant that a waterbody can receive and still meet water quality standards, and 2) an allocation of that amount to all of the pollutant’s sources. Another way to look at this is that a TMDL is the sum of the allowable loads of a single pollutant from all of the point and nonpoint sources (EPA, 1994).

DATA COLLECTION AND ANALYTICAL METHODS

The ability to assess environmental problems, compare them, and select strategies to reduce them all depend on the availability of relevant data and analytical tools. Sound data to evaluate risks and establish priorities did not --- and in many cases still do not --- exist in the Animas. In addition to the lack of data, inadequate methods for prioritization impeded the project on the Animas. As long as there are large gaps in key data sets, efforts to evaluate risk and establish priorities in a consistent, rigorous manner necessarily will be incomplete and the results of remediation will be difficult to interpret.

Streams and Tributaries

The Animas River Watershed is representative of a typical high-altitude stream system in the Rocky Mountain region. Three major tributaries of the Animas River flow together near the town of Silverton, Colorado: the Upper Animas converges with Cement Creek in the northeast part of town and Mineral Creek flows into the Animas just downstream of Silverton. The Upper Animas and Mineral Creek flow through ring faulted areas circling the ancient Silverton volcanic caldera. Cement Creek flows through the middle of the old caldera which was hydrothermally altered, fractured and mineralized several million years after the formation of the caldera. (Church, et al. 1997) Normal high flow occurs in June and July in response to snowmelt in the high San Juan Mountains. Low flows occur in late winter and late summer except for dramatic late summer monsoonal storms. We found that each of these three tributaries carried approximately the same metals load. However, Cement Creek had the lowest flow and therefore the highest concentrations of metals. “Water quality conditions over a large area are a function of complex natural and man-made causes and of the resulting interaction in both time and space.” (Sanders, et al, 1983).

Preliminary Surface Water Quality Studies. Initial reconnaissance of the basin was performed by the Colorado Department of Public Health and Environment, Water Quality Control Division (CDPHE) in 1991, 1992 and 1993. Synoptic surveys (a snapshot in time) were undertaken for each of the three main streams. Sampling points were immediately upstream and downstream of tributary streams, no attempt was made to identify or sample individual sources of metal loading at this time. Field parameters of pH, temperature and specific conductivity were taken at each sampling location. Grab samples were taken for water quality and filtered (0.45 micron filter) in the field using a hand pump and were analyzed at the CDPHE laboratory for dissolved metals. filtered (0.45 micrometer filter) in the field using a hand pump and were analyzed at the CDPHE laboratory for dissolved metals. Velocity-area flow rates were estimated using current meters and random sediment samples were collected using a standard U.S. U-59 suspended sediment sampler across the width and depth of the stream cross-section resulting in a sample that is actually a depth- and width-integrated composite of the cross section. We expected that low flow would exhibit the lowest pH values (due to less dilution) and snowmelt would exhibit the highest values (due to more dilution). The opposite was observed: mean pH for storm flow was lowest (5.0) and the mean pH for low flow was highest (5.5). In contrast, dissolved Zn concentrations in Cement Creek were highest during snowmelt and lowest during low flow, but the Zn loads were highest during snowmelt and lowest during low flow. (Owen, 1997) This data did show that although Cement Creek had the lowest flow of the major tributaries, its contribution to loading of the Animas was similar to both Mineral Creek and the Upper Animas. As in other watersheds, the diurnal fluctuations in flow necessitated sampling at the same time of day or on the same day within a very short time frame in order to compare results. Also the installation of flow gauges on each of the major tributaries assisted in interpretation of metals mobilization during different flow regimes. Shared data from split sampling showed that the diameter of the filter (although each agency used 0.45 micrometer filters) and the source of hydraulic pressure (be it by hand pump or electric pump) produced very different results. The ARGS determined that all of the samples to be compared in a prioritization needed to be collected using the same methodologies.

Sediment and Colloidal Sampling. The U. S. Geological Survey (USGS) found in the October 1995 synoptic sampling that iron colloids were forming and metals were sorbing to the colloids thus enhancing the solids partitioning of toxic metals. These particles had a strong tendency to aggregate thus precipitating on or binding to the surfaces of rocks and sand grains in the stream bed. With ultra-filtration the USGS found the diameter of the iron colloids ranged from greater than a few micrometers to less than one nanometer. Although in regulatory terms, most colloidal material is considered to be dissolved because it passes through a 0.45 micron filter. Low and high flow monitoring in 1996 showed the dominance of colloidal transport processes during high flow (10:1 ratio) and the greatest loads of both dissolved and colloidal metals occurred at high flow. Whereas, metal load from Cement Creek was primarily dissolved rather than colloidal in part because of the low instream pH of 3.9. Enrichment factors for metals in modern bed sediments, relative to those sediments that are clearly pre-mining in age, range from a factor of two to six for arsenic, four to more than 10 for cadmium, two to more than 10 for lead, two to five for silver, and two to more than 15 for Zn. The mining related sediments were determined to be primarily tailings materials discharged into the streams. (Church et al, 1999) We were unable to determine whether the dissolved metals or the sediment limited the ability for fish to reproduce and grow within the Upper Animas watershed (ARGS, 1999).

Toxicity Tests. Toxicity tests were conducted during 1997 with water and sediment from the main-stem and tributaries of the Animas River. Initial tests using 48- and 96-hour lethality tests indicated that both surface and subsurface waters from Cement Creek were toxic to daphnids, minnows, and trout. The toxicity of stream sediment was tested in the laboratory using 10-day tests with *H. azteca* and the midge *Chironomus tentans*. Trends in sediment toxicity were similar to those observed in the water-phase tests; however, the overall magnitude of effects was less in sediment tests than in water-phase tests. Also, concentrations of Cu in tissues of invertebrates and fish corresponded most closely to observed impacts on biota (Nimick, 1998).

Tracer Studies. The USGS injected tracers into Cement Creek during low-flow in September of 1996 just upstream from the American Tunnel at Gladstone. The purpose of this effort was to make more accurate calculations of flow and metals loading both in the surface and the alluvium of the creek. Discharge was measured by adding non-reactive tracers of sodium chloride and lithium chloride injected at constant rates for a sufficient time to get to a steady state, measuring the dilution of the tracer as it moved downstream, and calculated discharge from the amount of dilution. Eight principal sources of metals loading to the mainstem of Cement Creek were identified as shown on Figure 2 and in Table 1.

Figure 2 Cement Creek, major tributaries and key sampling locations. (ARGS, 1999)

Table 1 Gain and Loss of Dissolved Metal Loads for Selected Areas of Cement Creek, Colorado
 (All values , gain "+" and loss "-", in percent of the total load unless indicated: milligrams per second mg/s)

AREA	Copper (Cu)	Zinc (Zn)	Iron (Fe)	Aluminum (Al)	Manganese (Mn)	Sulfate (SO ₄)
Upstream from American Tunnel	12.3	10.7	0.1	1.4	1.9	0.3
North Fork area	31.4	7.8	2.4	4.1	1.7	2.2
American Tunnel/Sunnyside Mine	-42.0	-12.3	-2.4	-5.0	15.3	11.6
South Fork Area	3.9	8.5	2.1	1.7	9.6	7.1
Prospect Gulch Area	14.5	12.2	29.4	23.4	12.4	9.9
Minnesota Gulch Area	3.1	5.4	12.0	6.8	8.6	7.5
Porcupine Gulch /Anglo-Saxon	3.9	7.1	2.6	6.6	7.3	9.2
Ohio Gulch	9.8	11.2	13.1	12.9	11.4	8.3
Illinois Gulch	-3.6	-8.4	-21.2	-8.8	-5.8	4.8
Yukon Mine Area	5.8	3.9	1.9	3.0	4.8	-1.4
Topeka Gulch/MayDay Tailings	-.9	4.5	-3.5	2.0	-1.7	5.5
Lower Iron Bog (no mining)	3.8	8.6	15.9	15.0	7.5	9.1
Unsampled inflows (Groundwater)	56.0	42	46	58	24	31
Total Load in mg/s	77.0	95	799	4,820	2,370	372,000

(Kimball,et al, 1999)

Natural attenuation of metals occurred despite an instream pH of less than 4.5. Downstream of the high-pH discharge of the treated water from the American Tunnel, localized precipitation reactions occurred. Solute-transport models were then used to help interpret results from the tracer-injection study indicating that groundwater discharges are an important source of Zn to Cement Creek. (Kimball, 1999) Simulations of remediating, or "turning off," Zn-rich inflows from Prospect Gulch, a major tributary, predicts a decrease of about 25 percent at the mouth of Cement Creek compared to measured concentrations (Nimick, 1998).

Concentrations of Cu and Zn exceeded cold water aquatic life standards throughout Cement Creek except for a short reach downstream of the treatment plant on the American Tunnel. The North Fork, Prospect Gulch and upper Cement Creek (Fig. 2) contributed substantial loads of Cu and Zn, the metals of particular concern for aquatic life. Concentrations of Cu and Zn exceeded cold-water aquatic-life standards throughout Cement Creek except for a short reach downstream of the treatment plant at the American Tunnel (Herron et al, 1998). Prior to treatment and prior to tunnel sealing in 1996, the discharge from the American Tunnel from the Sunnyside Mine averaged about 3.5 cfs and contained about 15 mg/l of Zn (Owen, 1997). After tunnel plugging, treatment of the low flow discharges from the American Tunnel and the North Fork Cement Creek removed almost all of the Cu and Zn loads from both of these sources. However, the treatment plant discharged rather than removed both SO₄ and Mn. Inflows from the South Fork were relatively low in Fe and Al, but Cu, Zn, and SO₄ loads were substantial. A large increase of many metal loads occurred from a broad area around Prospect Gulch. The "Lower Bog" area which appears to be unaffected by mining contributed moderate levels of Cu and Zn and substantial Fe and Al second only to Prospect Gulch. Sources of this metal loading have not yet been documented, but the loads may come from a combination of natural sources and a mill and smelter complex immediately up slope. Unsampled inflows, thought to be primarily subsurface or groundwater flows, are the largest overall contributors of metals loading in all of the aforementioned categories (Kimball, et al, 1999). These metal loads from groundwater into Cement Creek may originate from natural background or from flooded mine workings. "The fractured, jointed highly alter nature of the bedrock could be allowing seepage from the adits to enter the groundwater system" (Herron, et al, 1999).

Table 2 CEMENT CREEK ADITS - DISSOLVED HIGH FLOW (H) / LOW FLOW (L) LOADS ¹

Stream & Site	pH	Cond ²	Flow ³	Cd	Cu	Zn	Al	Fe	Mn	Pb
Upper Cement										
Black Hawk	nd 7.29	nd 1200	0.845 0.20	1.86 0.88	8.28 0.00	592.09 285.62	0.00 0.00	165.62 24.35	881.93 1,244.89	0.00
South Fork										
Silver Ledge	6.14 6.28	560. 1050.	2.456 0.89	42.1 24.5	0.00 685.96	9874.23 1,555.79	17311.5 1674.62	138215.08 27,801.38	14,585.7 5,109.35	55.36
Big Colorado	5.24 4.56	685. 825.	0.015 0.04	? 0.42	? 2.15	? 95.86	? 597.47	? 6,610.50	? 194.92	? ?
North Fork										
Queen Anne	6.26 6.37	144	0.083 0.05	0.81 1.18	12.40 10.90	179.96 281.16	9.35 13.60	15.25 15.75	80.73 159.85	1.85 0.21
Grand Mogul	3.34 3.43	294. 510.	1.356 0.02	4.53 66.4 4	131.80 2415.24	12415.06 869.25	6710.84 516.00	37.39 14787.11	36.82 4508.23	97.34 1.98
Mogul	2.61 2.89	722. 1098.	0.060 0.02	17.4 9 9.17	793.07 379.50	3704.40 1730.78	543.17 294.12	6578.25 2845.74	1057.67 572.16	38.07 10.72
South Mogul ^H	3.00	706	0.03	2.06	146.34	390.73	434.53	3,584.60	139.06	3.99
Red & Bonita ^H	3.01	879	0.01	3.09	43.28	579.67	358.95	1,234.82	831.92	3.50
Dry Gulch										
Mammoth T.	5.76 4.90	982. 1464.	0.065 0.38	0.46 0.23	11.63 0.00	163.39 177.90	1140.07 304.29	13537.84 9,432.11	349.08 779.12	0.00 0.24
Prospect Gulch										
Joe & Johns	2.92 2.71	722. 1350.	0.034 nd	5.25 0.01	93.38 0.13	1006.26 2.62	711.22 3.30	4793.08 15.26	10.83 0.07	128.1 0.13
Henrietta 7 ^H	2.80	49	0.10	3.96	42.07	776.00	553.79	12,095.36	26.23	1.56
Lark Mine ^H	2.71	60	0.01	7.11	353.39	1,620.23	103.84	2,110.92	4.82	32.84
Georgia Gulch										
Geo. adit	7.05 7.05	1257. 1501.	0.385 0.38	0.00 0.00	0.00 3.09	268.83 175.37	0.00 0.00	3427.77 3,280.66	1579.00 1,623.63	0.00
K.C. #1	6.44 3.02	166. 1431.	0.022 ?	0.08 0.04	1.56 0.00	19.30 12.27	0.00 14.76	4.26 84.20	89.20 46.45	0.57 0.15
K.C.#2 ^H	6.11	270	0.02	0.46	2.62	52.48	3.19	89.63	74.71	0.11
Porcupine G.										
P.G. Adit	6.43 6.58	1359. 1526.	0.120 0.09	1.23 0.52	5.29 0.34	907.87 477.36	139.65 26.40	6135.78 89.69	4371.78 2,516.37	0.00
Anglo Saxon	6.63 6.61	1510. 1692.	0.131 0.09	1.57 0.68	9.63 1.32	1028.00 659.27	111.69 76.19	10331.38 6,948.41	2832.38 2,083.26	1.22
Illinois Gulch										
Yukon	6.72 7.08	997. 953.	1.210 1.21	0.00 0.00	0.00 3.18	352.78 293.02	0.00 0.00	809.31 3,284.49	2107.76 3,115.39	0.00

¹ - Load in (grams/day) ² - Specific conductance in (umhos/cm) ³ - Flow in g (cfs) ^H - Only high flows recorded (Herron et al., 1998)

Stormwater Study. A subsequent tracer study in Prospect Gulch provided additional insight into flows and loading during a late-summer storm event (Wirt, et al, this volume). Starting under base flow conditions, a sodium chloride tracer was injected and concurrent synoptic sampling undertaken. The storm dramatically increased the loads of most dissolved and total constituents. The first flush contained the highest loads of dissolved Fe, Zn, Cu, and Cd probably due to weathered mineral salts on the dump surfaces. Peak storm runoff contained the highest load of total Fe but other metals had decreased. Stormwater loads generally increased by one to two orders of magnitude over base-flow condition. The greatest downstream gains in dissolved metal loads occurred where waste-rock dumps were adjacent to the stream.

Draining Mines

Inventory of Sites. Starting in 1991 the Colorado Geological Survey sent teams to locate and characterize abandoned mines on land managed by the U.S. Forest Service. Similarly, the Bureau of Land Management used the U. S. Bureau of Mines to inventory abandoned mine sites. Specific data about mine openings, waste rock, tailings, and field parameters of pH and conductivity were taken to determine relative water quality. If field tests indicated poor quality water, a sample was collected for laboratory analyses (Owen, 1997).

Synoptic Sampling. The Colorado Division of Minerals and Geology (DMG) conducted a more comprehensive reconnaissance in 1996 and 1997 of specific sites resulting in a reclamation feasibility investigation (Herron, et al, 1998). Water samples were collected at 67 different sites along Cement Creek from one to four times during each of four sampling events representative of high and low flows. Water quality samples were collected by a team comprised of individuals from various governmental agencies and volunteers. Flow measurements, dissolved (45micrometer) and total recoverable metals were obtained.

Mine Wastes

Synoptic Sampling. Waste rock sampling of 44 different locations were conducted by the DMG in October 1996. A 2:1 rock to water volumetric extract was collected in the field. The extract was analyzed for field parameters, a portion was analyzed in the laboratory for heavy metals (Herron, et al, 1998).

PRIORITIZATION

A committee of technical experts from the ARGS evaluated the data supplied by these various studies and identified sites where opportunities for relative risk reduction by remediation existed. Primary sources of pollution within Cement Creek are mine drainage, waste, rock and tailings. Our basic assumption was that not all mines are created equal: the mineralogy, mining methods, water flow patterns and background geochemistry all effect the potential for problems resulting from the mining activity. Also, we assumed that not all metal loading originated from mining but major opportunities for reducing metals loads were mining related.

On a watershed scale, we used the CDPHE synoptic sampling at both high and low flows for instream concentrations of total and dissolved metals. This showed that all three of the major tributaries to the Animas, (Mineral, Cement and the Upper Animas) all had metal loads from inactive and abandoned mines and mills. We decided to proceed in a step-wise fashion of one subwatershed at a time. Prioritization of Mineral Creek was relatively easy because we had very little data upon which to make decisions. For Cement Creek it became more of an issue of what data was available for use. The DMG synoptic sampling, mine drainage and mine dump sampling became available first. First we looked at the loads being carried instream for Cu, Zn, and Cd. To visualize the relative importance of each stream segment of importance based upon loading of each chemical Cu, Zn and Cd high being ranked from 1-5; medium 6-10; and low greater than tenth place. (Figure __) The mine drainage loads were portrayed in the same manner. The committee then evaluated the alternative mine sites against the following set of defined criteria

Environmental Impact (high, medium and low)-

- Dissolved Zn and/or Cu. (Zn was useful because it was assumed to be nonreactive at current instream pH values from 6.5 to 3.5).
- Dissolved Fe as an indicator of acidity.
- Existing or potential aquatic life in nearby streams
- Water quality impacts at the point of compliance downstream of Silverton

Technical feasibility of remediation:

- Cost effectiveness.
- Treatability/feasibility.
- Cultural and historic preservation.

Options for remediation are a key component of setting priorities. Site specific remediation options must be considered in order to determine cost effectiveness; treatability/feasibility; and cultural and historic preservation options. Primary sources of pollution within Cement Creek are mine drainage, waste rock, slag and tailings. Natural-background metals loading is not considered to be pollution. We first looked at simple treatment options such as hydrological controls (preventative measures) such as diversion ditches, mine waste removal from flow paths, stream diversion, bulkhead seals, capping and revegetation. Passive treatment of acid rock drainage was then investigated using anoxic limestone drains, settling ponds, sulfate reducing wetlands, nutrient injection, aqueous lime injection, limestone water jet, oxidation wetlands, aeration, powered mechanical neutralization systems, dilution, electro-kinetics and land application. (Herron et al,1998)

Mine Drainage Prioritization

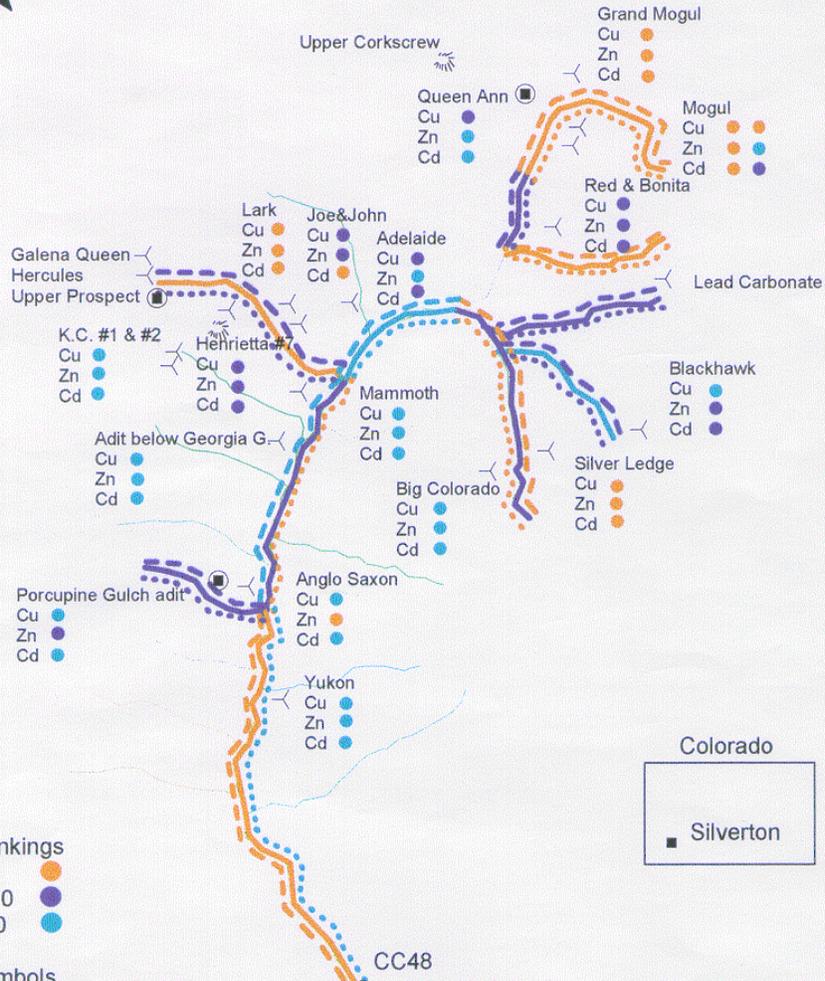
Mine drainage treatment is complex in that all waters do not necessarily flow from the adit. Groundwater flow through fractures, adjacent mine workings and alluvium may be a large component of the discharge of pollutants. Therefore mine drainage and releases from waste rock piles were separated in the prioritization. Each criterion was assigned a weight or value a multiplication factor based upon the chemical potential for toxicity: Cu, Cd, and Zn (3); Pb, Mn (2); Fe and Al (1) and biological potential of the nearest stream segment (4). In a similar manner, low flow and technical feasibility of remediation were ranked (Table 3). Site specific remediation options were considered in setting priorities in order to determine cost effectiveness; treatability/feasibility; and cultural and historic preservation options. Cost per pound of metals removed (cost effectiveness) was not ranked at this time because fluctuations in costs create the need for routine reevaluation of this factor. Costs will be taken into consideration at the time of final prioritization taking into account willing landowners and money availability. The following remediation options were weighed in setting priorities: Technical feasibility of remediation: Treatment Methods = Hydro-control (4); Passive treatment (3); Unknown (2) and Active treatment (1). Access: to site easy (3) moderate (2) difficult (1). Preventative treatment options of hydrological controls are preferable because they tend to be cheaper and easier to install. Hydrological controls include actions such as diversion ditches, mine waste removal from flow paths, stream diversion, bulkhead seals, capping and revegetation. Passive treatment of acid rock drainage is preferred as a second option for remediation. Passive treatment includes: anoxic limestone drains, settling ponds, sulfate reducing wetlands, nutrient injection, aqueous lime injection, limestone water jet, oxidation wetlands, aeration, low maintenance mechanical neutralization systems, dilution, electro-kinetics and land application (Herron et al, 1997).

Table 3 Ranking of environmental impact of Cement Creek draining mines during high flow.

Site Factor	Cd H* (3)	Cu H (3)	Zn H (3)	Al H (2)	Fe H (2)	Mn H (1)	Pb H (1)	pH H (2)	Bio. Pot (4)	Total #	Rank
Black Hawk	3	6	6	4	2	1	1	2	12	37	8
Silver Ledge	9	9	9	6	6	3	3	2	12	59	1
Big Colo.	3	3	3	2	2	2	1	4	12	32	11
Queen Anne	6	3	3	2	4	1	1	2	4	26	13
Mogul	9	9	9	4	6	2	2	6	8	55	2
South Mogul	9	6	3	2	4	2	2	6	8	42	5
Red & Bonita	6	6	6	4	4	2	1	4	8	41	5
Mam. Tunnel	3	3	3	4	2	2	3	4	4	28	12
Joe & Johns	6	9	9	2	6	3	2	6	4	44	4
Hen. #7	6	6	6	2	4	3	3	6	4	40	7
Lark Mine	9	9	9	2	6	1	1	6	4	47	3
Kansas City #1	3	3	3	2	2	1	1	2	8	25	14
Kansas City#2	3	3	3	2	2	1	1	2	8	25	14
P.G. A dit	3	3	6	6	2	1	2	2	8	33	10
Anglo Saxon	3	3	9	6	4	1	3	2	4	35	9
Yukon		3	3	6	2	1	1	2	4	25	14

* High flow only

(ARSG, 1999)



Stream Segment and Mine Discharge Rankings for Cement Creek - High Flow Dissolved Copper, Zinc, and Cadmium

Animas River Stakeholders Group
Silverton, Colorado

Figure 3 Cement Creek stream segment and mine drainage rankings - high flow dissolved Cu, Zn and Cd.
(ARSG, 1999)

Mine drainage treatment is complex in that all water does not necessarily flow from the adit. Groundwater flow through fractures, adjacent mine workings and alluvium may be a large component of the discharge of pollutants. Therefore active treatment was ranked last in preference because of the technical difficulties as well as cost both for construction and for operation and maintenance. Cultural and historic prioritization will be factored into the prioritization by the San Juan County and the San Juan Historical Society at a later time (ARSG, 1999).

Mine Waste Prioritization

Prioritization of mine waste is currently under development. Factors to be considered will be similar to those for draining mine adits. Release of metals from mine waste to receiving waters is not well understood. The USGS is conducting studies of the mineralogical, chemical and physical characteristics of mine wastes. Also underway is research regarding physical or microbiological weathering that enhance or reduce metals releases. Two mine dumps near Cement Creek, the May Day and the Yukon, the targets for some of these studies (Nimick, 1998). From these preliminary studies, the factors to be considered for mine waste prioritization are: the leaching chemistry of composite surface samples, chemistry and volume of seeps from the waste materials, the biological potential of the nearby stream, the proximity of the waste to water, acid mine discharges onto the surface of the dump, the horizontal projection of the surface of the pile, and if erosion is evident.

CONCLUSIONS

A quantitative approach to reducing and managing contaminant loading in the Animas Watershed will produce more cost effective and more acceptable selection of remedial technologies to meet the defined water quality goals. This is a work in progress. ARSG's homepage at www.waterinfo.com/ARSG provides currently available information on the watershed effort. Improved data on the potential risks to the environment of metals concentrations and loading will help focus this prioritization effort. Also as remediation takes place, validation of the risk predictions will help in future assessment, comparison, and reduction of different environmental risks. Although setting priorities for environmental protection efforts always will involve subjective judgments, the ARSG works continually to improve the scientific data and analytical methodologies that underpin those judgments and help reduce their uncertainty.

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